



Breeding success and abundance of UK Little Terns in relation to conservation management 2009-2023

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Linda J Wilson¹, Leigh Lock² and Mark Bolton¹

¹ RSPB Centre for Conservation Science; ² RSPB Global Species Recovery

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2. Summary

Little Terns have undergone a long-term population decline in the UK since the mid-1980s and are one of our rarest breeding seabird species. Consequently, they have been subject to intensive management measures designed to improve their breeding success. A five-year large scale recovery programme across key sites in England and Wales was initiated in 2014, including enhanced wardening, predator management, habitat management and habitat creation. This resulted in immediate positive impacts on breeding success, although the increase was sufficient only to slow rather than halt the population decline. Since then, a Little Tern Recovery Plan was established and subsequent projects have continued with coordinated enhanced management, mainly focussing on sites in England and the two breeding sites in Wales, though more recently since 2022 also including coordinated approaches in Scotland (there are no Little Terns breeding in Northern Ireland).

Here we review the most recent Little Tern breeding success and abundance data to assess how these parameters have varied recently compared to previous levels, to inform discussions on the conservation strategy for this species. Overall, the available evidence shows that the enhanced management measures put in place since 2014 in England and Wales have coincided with an improvement in breeding success and an increased probability that sites in these countries will achieve a level of breeding success sufficient for population stabilisation. Furthermore, the population trend in England is less negative than previously, and there are signs that it may be stabilising or perhaps even increasing. We found a continued decline in both breeding success and abundance in Scotland, which is consistent with large-scale enhanced measures only being implemented since 2022. We recommend continued targeted conservation action at colonies to improve breeding success and creation of new safe sites to secure longer term recovery.

3. Introduction

Little terns are one of the UK's rarest breeding seabird species, with a population of 1,403 Apparently Occupied Nests (AON) recorded during the recent Seabirds Count census (Burnell et al. 2023). This represents a decline of 25% since the previous Seabird 2000 census, and a decline of 46% since the Seabird Colony Register census during 1985-88 (Burnell et al. 2023, Mitchell et al. 2004). These declines have occurred despite Little Terns being one of the most intensively managed seabird species in the UK, with a variety of conservation measures being deployed over the decades (Smart 2003). Declines have been attributed to reductions in breeding success and subsequent recruitment rather than to emigration or changes in adult survival (Pickerell 2004; Ratcliffe et al. 2000; Ratcliffe 2003), so conservation action has focussed on measures to improve breeding success.

Between 2014-2018, the EU LIFE+ Little Tern Recovery Project deployed increased management resources across 29 of the most important UK Little Tern Special Protection Areas (SPAs) - all in England and Wales - under four broad management areas: (i) an enhanced warden scheme; (ii) predator management; (iii) habitat management and enhancement for existing colonies; and (iv) habitat creation/restoration to support new colonies. An end-of-project review found that immediate positive impacts on little tern breeding success were apparent during the project's lifetime, however at that stage the overall increase in average breeding success was sufficient only to slow, rather than halt or reverse, the population decline (Wilson et al. 2020).

Following the conclusion of the Little Tern LIFE+ project, every effort was made to continue to implement the best conservation interventions at as many sites as possible. However, in the absence of a single funding programme, funding at individual sites was variable and uncertain, but action was coordinated through the Little Tern Steering Group which included representatives from England, Wales, Scotland, and Republic of Ireland. In England from 2020 significant additional funding and coordination was provided through initiatives working in combination. [LIFE on the Edge](#) (LOTE, 2020-2025) focussed on habitat creation and restoration at key shorebird sites, and developing species recovery programmes including for Little Tern, as well as knowledge-sharing and advocacy, while Natural England's Action For Birds in England (AFBIE) funded Beach-nesting Birds programme (BNB, 2023-2025) supported work at multiple sites. This has provided a significant shift in the resourcing for protection and management in England. In Scotland, since 2022 the [Terning the Tide](#) project within the Species on the Edge programme has also been ensuring that Little Tern sites are protected and better monitored. In Wales, site management at the principal colony at Gronant has continued at the same level as established during the LIFE+ Little Tern Recovery Project.

With this step change in enhanced management measures for Little Terns being in place in England and Wales over the last decade, and more recently established in Scotland, there is a need to revisit how Little Tern populations are faring across each country to inform discussions on the conservation strategy for this species. In this report, we review the most recent Little Tern breeding success and abundance data to assess how these parameters have varied recently compared to previous levels. The situation in England is of particular interest given this is where most of the large-scale conservation projects have been directed and thus where we would expect to see most improvement. Therefore, we focus on the last fifteen years, splitting these into three five-year periods that correspond to different management regimes, defined by the timing of the EU LIFE+

project that was implemented at key SPAs in England and Wales: 'Baseline', or business-as-usual, (2009-2013), 'LIFE' (2014-2018) and 'post-LIFE' (2019-2023)¹. Specifically, we assess whether the following has occurred during the LIFE and post-LIFE periods compared to the Baseline period:

- (1) Has breeding success improved?
- (2) Has there been an increased probability of sites achieving breeding success of 0.7 chicks per pair (i.e. the level required for population stability, Cook & Robinson 2010)?
- (3) Has the population trend become less negative?

¹ Technically the 'baseline' or business-as-usual period in Scotland spans 2009-2021 (i.e. until the start of the Terner the Tide project. However, we use these time period definitions here given the situation in England is of particular interest.

4. Methods

4.1. Breeding success

4.1.1. Assessing whether breeding success has improved

We obtained a country-level overview of how Little Tern breeding success has varied over time using the most recent Little Tern breeding success trend statistics from Harris et al. (2024), which are produced by BTO and available from the BTO's [trends explorer](#) webtool². Annual estimates were calculated using Generalised Linear Mixed Models (GLMMs, see Harris et al. (2024) for method details).

The breeding success trends provided by Harris et al. (2024) are only available at a UK, England and Scotland level and no trend statistics are available for Wales, so we also obtained site-level breeding success data for 2009-2023 from the Seabird Monitoring Programme (SMP) database (data received from BTO 25 April 2024). In the past, data entered directly into the SMP database by site managers were supplemented by the database manager with data available from RSPB Little Tern Annual newsletters. However, a reduced number of site records since 2018 in the SMP dataset indicated these additional data had not been entered by April 2024. Therefore, additional data from the RSPB Little Tern newsletters from 2019-23 were identified and added manually by LW. Data were available at a site level, with a single peak count of fledglings ("Fledged") and a single peak count of AONs ("Count") which represented colony size in pairs.

To formally assess whether breeding success has improved, we used the site-level data to compare breeding success across the three five-year time periods: 'Baseline' (2009-2013), 'LIFE' (2014-2018) and 'post-LIFE' (2019-2023). We fitted a negative binomial GLMM, modelling the response as the number of chicks fledged per site ('Number Fledged') and accounting for the different numbers of nests at each site by including colony size (fitted as the natural logarithm, \ln , of "Count") as a covariate. An alternative would have been to fit $\ln(\text{Count})$ as an offset term, however, an offset would force the coefficient of $\ln(\text{Count})$ to be 1 so by instead fitting $\ln(\text{Count})$ as a covariate, this provided more flexibility. Specifically, it allowed us to also assess whether the rate at which the number fledged per site increases with colony size gets greater (rather than stays constant) as colony size increases (i.e. whether the coefficient of $\ln(\text{Count})$ is >1). This was of interest as Wilson et al. (2020) previously found a positive effect of colony size on breeding success.

Thus, to test whether breeding success had improved with time period, we fitted a GLMM with Number Fledged explained by Time Period, fitted as a three-level factor (Baseline, LIFE and post-LIFE), and $\ln(\text{Count})$ as fixed effects. Preliminary analysis showed models were over dispersed so we specified a negative binomial distribution (with quadratic parameterization to allow the variance to increase quadratically with the mean) and included a zero-inflation term for $\ln(\text{Count})$ to account for a high number of zeros (breeding failures) particularly at smaller colonies. Site was fitted as a random effect to account for repeated measures of breeding success across years. We also included

² Downloaded on 21 November 2024. Trends are updated when new data become available. The trends we show here are those used in Harris et al. (2024).

an interaction between $\ln(\text{Count})$ and Time Period to examine whether the relationship between the number fledged and colony size (i.e. the rate at which the number fledged increases with colony size) varied with Time Period.

To investigate effects at the individual country level, we included Country as a three-level factor (England, Scotland, Wales; there are no Little Tern colonies in Northern Ireland). We included an interaction between Country and Time Period to allow for the effect of country to vary among time periods.

The global model was therefore:

$$\text{Number Fledged} \sim \text{Time Period} + \ln(\text{Count}) + \text{Country} + \text{Time Period}:\ln(\text{Count}) + \text{Time Period}:\text{Country} + (1|\text{Site})$$

Little Tern colonies in the UK have previously been found to have two distinct regional groupings that differ significantly in their breeding success trends (Cook & Robinson 2010). Colonies in the southern region (encompassing East Anglia and the south of England) had slightly declining breeding success, while those in the northern region (encompassing the north of England, Scotland, Wales, and southeast Ireland) had relatively stable breeding success (Cook & Robinson, 2010). Wilson et al. (2020) also found a significant effect of region on breeding success, with colonies in the northern region performing better than those in the southern region. While Scotland and Wales both belong to the northern region, England includes both the northern and southern region. Thus, by including Country in the model, we were only able to partially control for regional effects. Therefore, for comparison we ran a second alternative global model that split England into two regions, to control for any regional effects within England. Effectively, in this alternative global model, Country was replaced by a four-level factor called Region. The results for this are presented in Appendix 1; we focus on the Country level results in the main body of the report.

4.1.1. Assessing the probability of sites achieving breeding success target

Cook & Robinson (2010) previously showed that the level of Little Tern breeding success required for population stability was 0.7 chicks per pair. We calculated the proportion of site-years that met this target over the three Time Periods. We then modelled the probability that a site met the target, with 'target reached' (yes (=1) or no (=0)) as the response variable and Time Period, Country and $\ln(\text{Count})$ as fixed effects, specifying binomial errors and a logit link function. The interaction terms of Time Period: Country and Time Period: $\ln(\text{Count})$ were included and Site was added as a random effect. This allowed us to assess the probability of the breeding success target being met in each Time Period, allowing for differences among Countries and controlling for any effects of colony size.

4.1.2. Analyses software and packages

Analyses were carried out in R 4.4.1 (R Core Team 2023) and models were fitted either using the `glmmTMB` package (for the model assessing whether breeding success has improved, Brooks et al. 2017) or the `lme4` package (for the target breeding success model, Bates, Mächler, Bolker, & Walker, 2015). Model residuals were checked for uniformity, overdispersion and zero-inflation using the `'simulateResiduals'` function of the `DHARMA` R package (Hartig 2018). All possible models were investigated using the `'dredge'` function in the R package `'MuMIn'`. Akaike's Information Criterion, corrected for small sample sizes (AICc), was used for model selection: the model with lowest AICc was deemed the best performing; those within two AICc units of the best were considered to show equivalent support (Burnham & Anderson, 2002). We used the `'predict_response'` function within the `ggeffects` R package (Lüdtke 2018) to make predictions and the `emmeans` package (Lenth et al. 2023) to carry out pairwise comparisons.

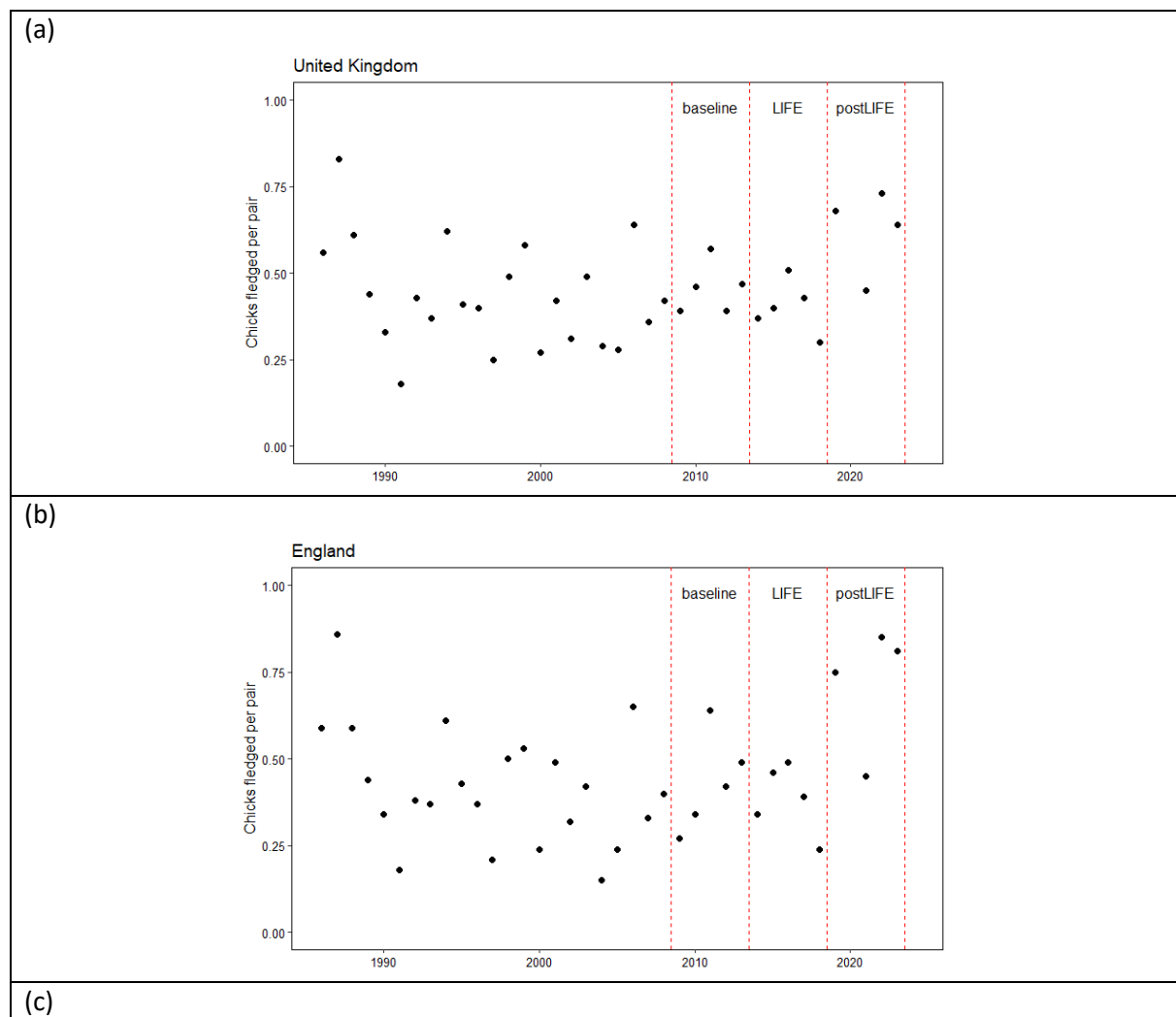
4.2. Population trends

To assess whether Little Tern population trends have become less negative since enhanced management has been implemented, we compared the 5-year abundance trend within each of the three time periods (Baseline, LIFE and post-LIFE). To do this, we used the most recent Little Tern population trend statistics from Harris et al. (2024), downloaded from the BTO's [trends explorer](#) webtool¹. These trends are produced by BTO and are provided as annual indices of abundance relative to the base year (1986). All sites within the Seabird Monitoring Programme (SMP) database with at least three colony counts submitted since its inception in 1986 are included in the annual trend analysis, and an imputation method (Thomas 1993) is used to estimate abundance for sites with missing years of data. Annual indices are then produced by scaling the total abundance in the base year (1986), with subsequent years represented as a percentage relative to 1986. Trends are available at a UK, England, and Scotland level only. See Harris et al. (2024) for a fuller description of the methods.

5. Results

5.1. Breeding success

The modelled annual breeding success estimates from Harris et al. (2024) show that breeding success was largely stable during the Baseline and LIFE periods across the UK and in England, with breeding success ranging from 0.24 to 0.64 chicks per pair (Figure 1). There was then an increase in breeding success during the post-LIFE period, ranging from 0.45 to 0.85 chicks per pair across England and the UK. In contrast, in Scotland there was a decrease in breeding success between the Baseline and post-LIFE periods (Figure 1). There are no modelled breeding success estimates available for Wales in Harris et al. (2024).



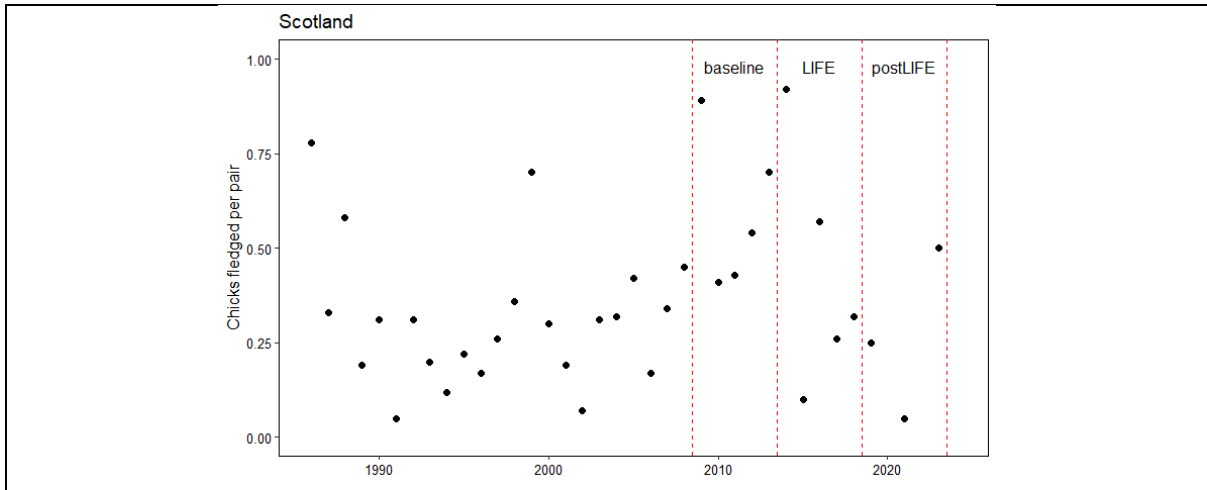


Figure 1. Modelled breeding success of Little Terns from 1986-2023 in (a) UK, (b) England and (c) Scotland, taken from Harris et al. (2024). The Baseline, LIFE and post-LIFE periods are indicated using vertical red dashed lines. No modelled data are available for Wales.

To investigate breeding success in more detail, we obtained site-level data from the SMP database and Little Tern newsletters for a total of 504 site-years, with 92 unique sites and a yearly sample size ranging from 26-47 sites (Table 1, Figure 2). Thirty-one sites had at least one year of data in each of the three time periods. Most (59%) of the sites were in England, while only 2% of sites were in Wales. The sample of sites varied greatly in colony size, ranging from 1 to 339 AONs, but data were heavily skewed towards small colonies, with most (81%) site-years comprising colonies of 50 AONs or fewer (Fig. 3a). Breeding success ranged from 0 to 2.5 chicks per pair, with complete breeding failure occurring in 36% of site-years (Figure 3b). Boxplots of the raw data show that median breeding success increased with each successive Time Period within England and Wales but decreased between the Baseline period and LIFE / postLIFE periods in Scotland (Figure 4). However, there was a lot of variation in breeding success within each Time Period and Country.

Table 1. The number of breeding success records for each country in each year used in the analyses. Site-years with no breeding attempts are excluded. For England, separate sample sizes are provided for the Northern and Southern region as defined by Cook & Robinson (2010); see Figure 2.

Year	England		Scotland	Wales	Total no. of sites
	Northern	Southern	Northern	Northern	
2009	4	19	13	1	37
2010	4	18	11	1	34
2011	4	19	12	1	36
2012	4	22	5	1	32
2013	5	21	9	1	36
2014	4	18	6	1	29
2015	8	25	12	2	47
2016	6	20	8	2	36
2017	6	18	6	2	32
2018	7	18	6	2	33
2019	6	19	13	2	40
2020	4	16	8	2	30

2021	4	14	6	2	26
2022	6	13	6	2	27
2023	5	18	4	2	29
No. of unique sites	9	45	36	2	92

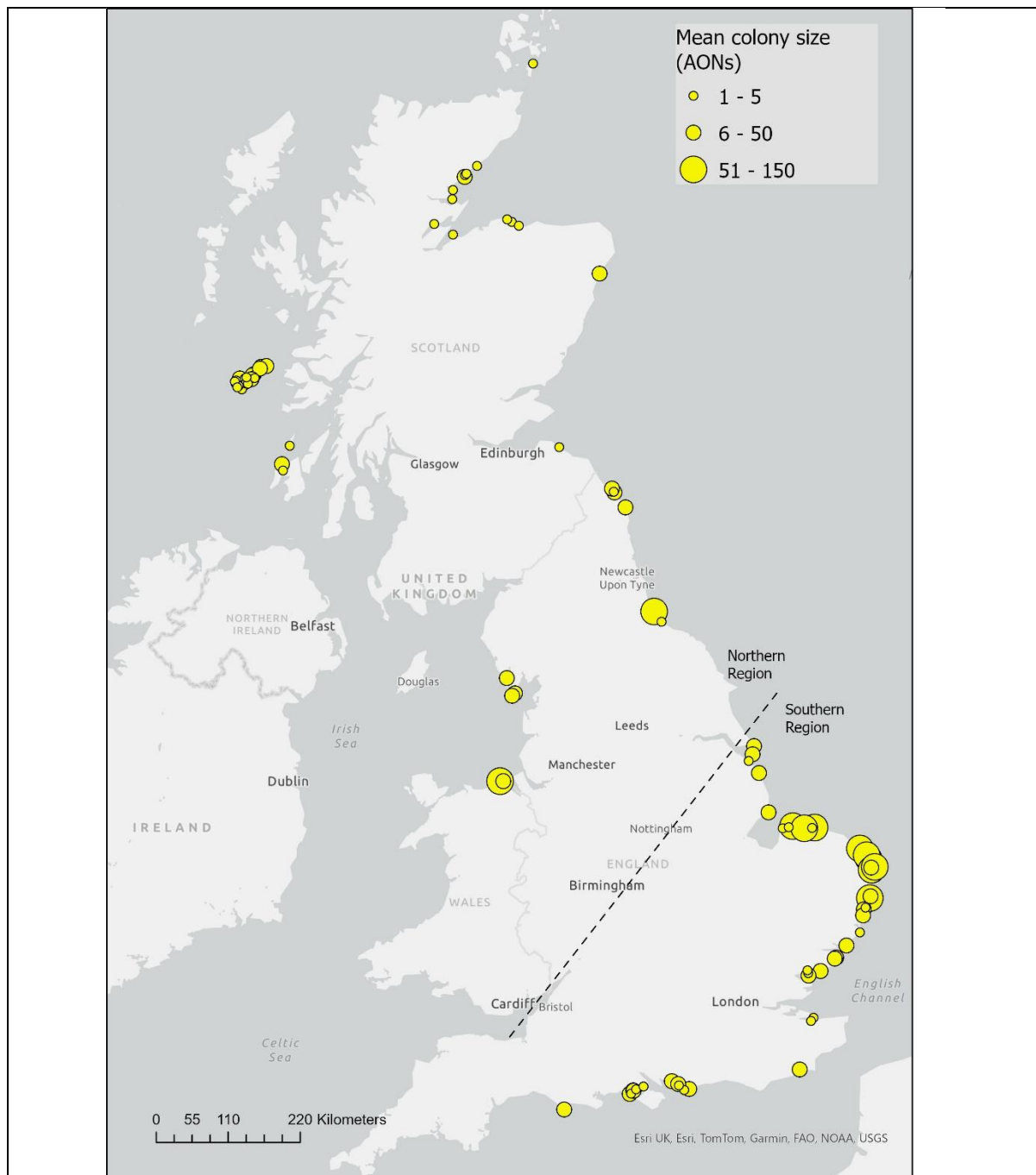


Figure 2. Map showing locations of Little Tern sites used in the breeding success analysis, and the boundary between the Northern and Southern Regions, as defined by Cook & Robinson (2010). Symbol size is proportional to mean colony size during 2009-2023.

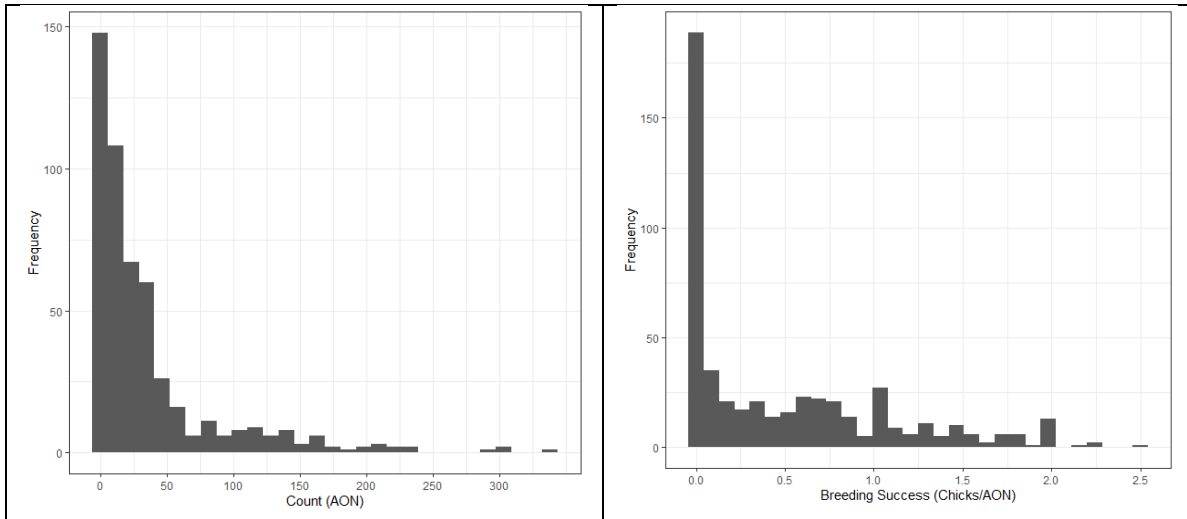


Figure 3. Frequency distribution of (a) colony sizes sampled and (b) observed breeding success across all sites and years.

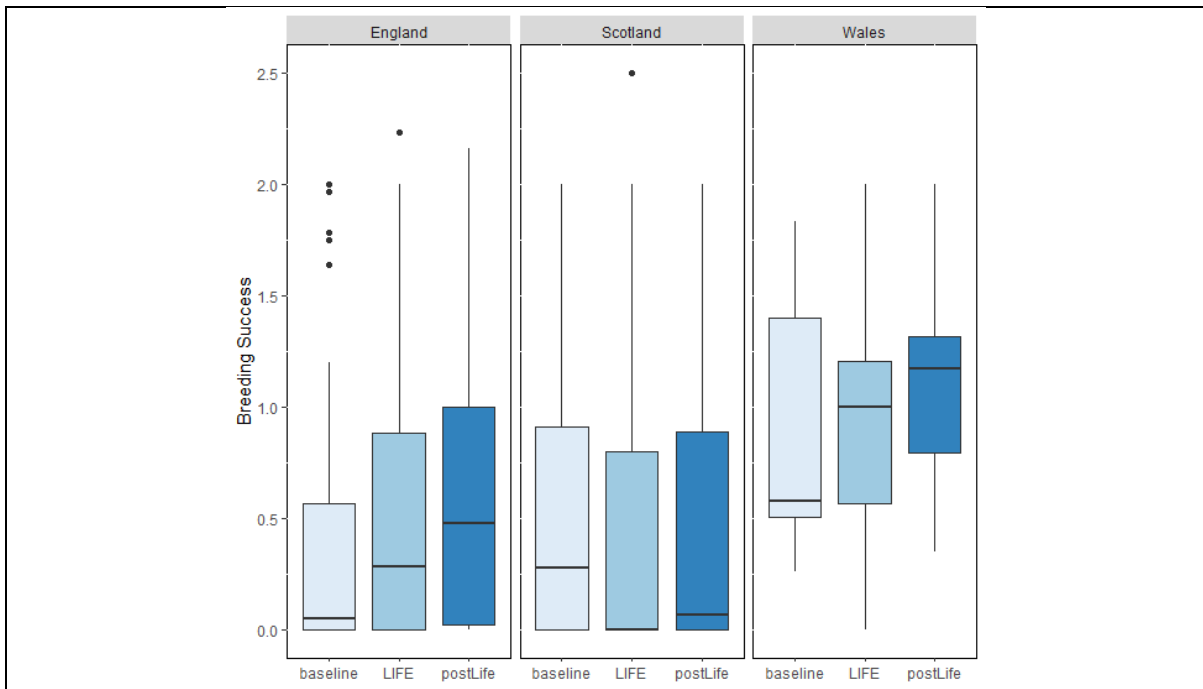


Figure 4. Boxplot showing the spread of breeding success values in the raw data for each Time Period (Baseline, LIFE and postLIFE) within each Country. Black horizontal lines represent the median value while the upper and lower edges of the box represent the upper and lower quartiles. Vertical lines show 1.5 x the inter-quartile range above and below the box. Individual points show outliers lying >1.5 inter-quartile ranges beyond the top and bottom of the box.

5.1.1. Assessing whether breeding success has improved

The analysis to assess whether breeding success has improved with Time Period identified three equivalent best performing models (Table 2). The top model (i.e. the model with the lowest AICc value) was the full global model. The second-best model had all the same terms as the global model bar the interaction term between Time Period and Country. The third-best model only contained

$\ln(\text{Count})$, Time Period and the interaction between them. All models showed a significant increase in the number fledged as colony size increases (as would be expected), with the rate of increase getting larger with increasing colony size (i.e. breeding success increases with colony size). The interaction term between Time Period and $\ln(\text{Count})$ in all three models indicate that the positive effect of colony size on the number of fledglings is less during the LIFE and post-LIFE periods compared to the Baseline period. The zero-inflation term in all models showed that the probability of a zero (no chicks fledged) decreases as colony size increases. All models also showed an effect of Time Period, but the interaction term between Time Period and Country in the global model shows that the effect varies by Country.

We made predictions using the top best-performing model (i.e. the global model) for each Time Period within each Country (Figure 5). Interpreting the global model is complex because it includes two interaction terms. An interaction term means that the relationship between two variables depends on the value of another. In our case, the relationship between the number of fledglings and time period depends not only on the country but also on colony size, so interpreting the relationship is context dependent. Therefore, for illustration purposes, we made predictions of the number fledged per site for three different colony sizes, the 10th percentile (1 AON), 50th percentile i.e. median (17 AONs) and the 90th percentile (108 AONs) in our dataset (Figure 5). For ease, we refer to these as small, median, and large colony sizes respectively. Please note however that in Wales only one colony existed during the Baseline period and this always had >115 AONs during this period, so predictions include hypothetical colony sizes.

Figure 5 highlights the overall positive effect of Time Period on breeding success in England and Wales compared to a generally negative effect in Scotland (note that here, breeding success refers to the number of chicks fledged per site rather than per pair). Specifically:

- For small colonies, there is an overall positive effect of Time Period on breeding success in all three countries - although there is a small reduction in mean breeding success between LIFE and post-LIFE periods, mean breeding success post-LIFE is still greater than during the Baseline period.
- For median colonies there is a positive effect of Time Period on breeding success in England and Wales, but a negative effect in Scotland.
- For large colonies, there is an overall positive effect of Time Period on breeding success in England and Wales - although there is a reduction in mean breeding success between the Baseline and LIFE periods, there is a subsequent increase during post-LIFE such that mean breeding success post-LIFE is greater than during the Baseline period. However, for large colonies in Scotland, there is a much larger reduction in mean breeding success between the Baseline and LIFE periods, with only a small subsequent increase during post-LIFE, resulting in an overall negative effect of Time Period in Scotland.

When interpreting Figure 5, it is important to note the wide confidence intervals around the mean estimates. While there may be changes in mean breeding success as described above, where there is a wide overlap in the confidence intervals around the estimates being compared, then overall breeding success can be considered as largely stable between time periods. The confidence intervals around predictions are much smaller for England than in Scotland or Wales, in part due to the larger

sample size of sites in England (see Table 1). To test whether the changes in breeding success between time periods were statistically significant, we carried out pairwise comparisons of breeding success for each pair of time periods within each country. These show that the change in breeding success is only significant between the Baseline and post-LIFE period in England (Table 3).

Table 2. Parameter estimates for models investigating the effect of Time Period, Colony Size and Country on the number of Little Tern chicks fledged per site. Only the three best performing models are shown. The reference value for Time Period is the Baseline period, while the reference value for Country is England.

		Model Rank		
		1	2	3
Conditional Model	Intercept	-1.865	-1.391	-1.209
	Time Period (LIFE)	1.739	1.164	1.121
	Time Period (postLIFE)	1.628	0.912	0.893
	Count (ln)	1.285	1.190	1.165
	Country (Scotland)	0.852	0.306	
	Country (Wales)	0.409	0.467	
	Time Period (LIFE): Country (Scotland)	-0.794		
	Time Period (postLIFE): Country (Scotland)	-1.015		
	Time Period (LIFE): Country (Wales)	0.123		
	Time Period (postLIFE): Country (Wales)	-0.004		
	Time Period (LIFE): Count (ln)	-0.405	-0.284	-0.280
	Time Period (postLIFE): Count (ln)	-0.299	-0.149	-0.150
Zero-inflation model	Intercept	0.114	0.186	0.192
	Count(ln)	-0.486	-0.503	-0.502
Df		16	12	10
logLik		-1480.4	-1484.8	-1487.5
AICc		2994.0	2994.2	2995.5
Delta AICc		0.00	0.16	1.45
weight		0.361	0.334	0.175

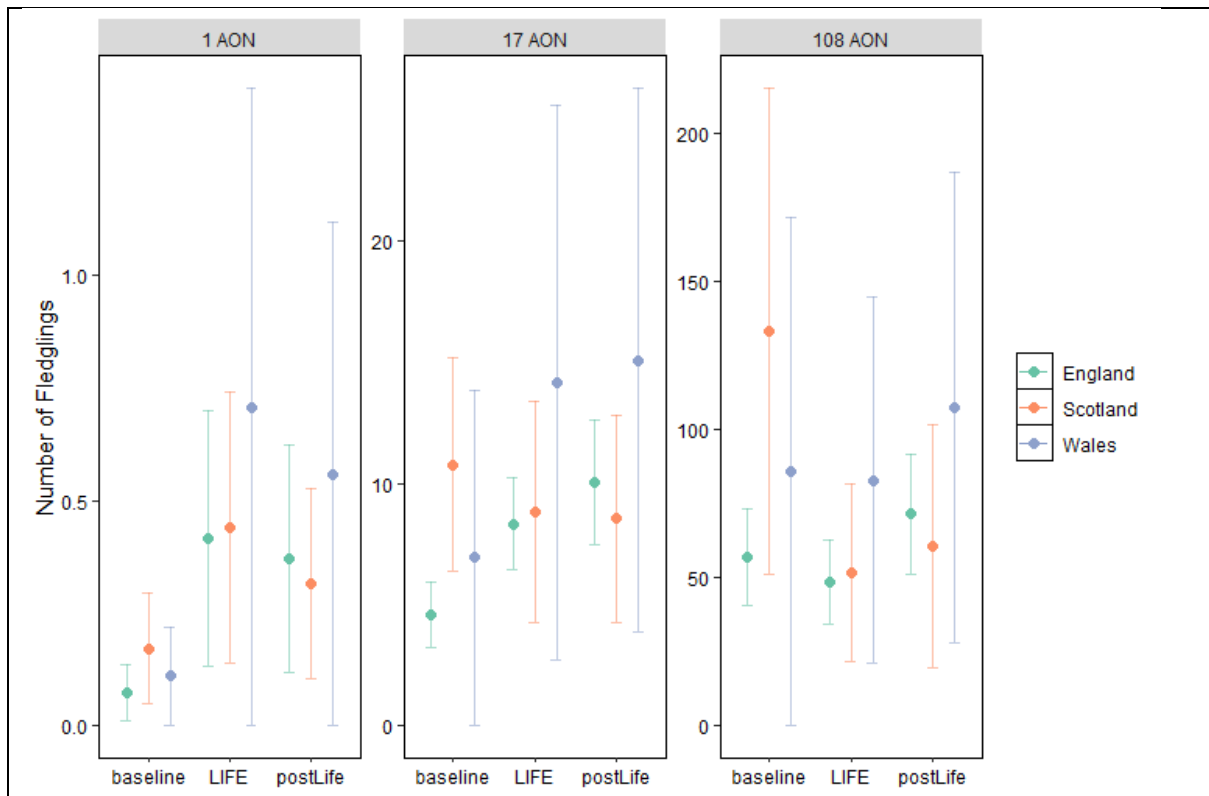


Figure 5. Predicted number of chicks fledged per site based on the top best-performing model for three different colony sizes: the 10th percentile (1 AON), 50th percentile i.e. median (17 AONs) and 90th percentile (108 AONs) across the dataset, for each Time Period within each country. Points and error bars show the mean predictions and 95% confidence intervals.

Table 3. Pairwise comparisons of Time Period within Countries for the top best-performing model using emmeans package (Lenth et al. 2023). Contrasts are performed while holding the covariate (colony size) at its mean value. The ratio between means for each group within the contrast is shown. A ratio >1 means that the first group has a higher mean than the second group, while a ratio <1 means that the first group has a lower mean than the second group. The null hypothesis is that the ratio =1 i.e. there is no difference between the means. P values are adjusted using Tukey method for comparing a family of 3 estimates, with tests performed on the log scale. The grey highlighted row denotes a significant contrast.

Country	contrast	ratio	st. error	df	null	Z ratio	P value
England	Baseline / LIFE	0.748064	0.107859	Inf	1	-2.01316	0.13
	Baseline / postLife	0.572306	0.085886	Inf	1	-3.71879	<0.001
	LIFE / postLife	0.76505	0.107181	Inf	1	-1.91163	0.17
Scotland	Baseline / LIFE	1.655578	0.535764	Inf	1	1.557887	0.36
	Baseline / postLife	1.578544	0.548877	Inf	1	1.312882	0.57
	LIFE / postLife	0.95347	0.345892	Inf	1	-0.13134	1
Wales	Baseline / LIFE	0.661702	0.329588	Inf	1	-0.82904	1
	Baseline / postLife	0.574478	0.285525	Inf	1	-1.11524	0.79
	LIFE / postLife	0.868183	0.371465	Inf	1	-0.33037	1

5.1.2. Assessing the probability of sites achieving breeding success target

For both England and Wales, the percentage of site-years where breeding success reached or exceeded 0.7 chicks per pair (the value previously shown to be required for population stability by Cook & Robinson 2010) increases with each consecutive Time Period, while for Scotland it decreases (Table 4). For the analysis testing for an effect of Time Period on the probability that a site achieved 0.7 chicks per pair, there was only one single best-performing model, the global model (Table 5). This confirmed an overall positive effect of Time Period on the probability of achieving the target for England and Wales, but a negative effect for Scotland (Table 5, Figure 6). Pairwise comparisons (Table 6) show that the effect of Time Period on the probability of achieving the target breeding success value was significant in England (for the Baseline/post-LIFE contrast) and Scotland (for the Baseline/ LIFE and Baseline/post-LIFE contrasts). Appendix 9.2 illustrates how the effect of Time Period on the probability of achieving target breeding success varies with colony size.

Table 4. The percentage of site-years where breeding success was ≥ 0.7 chicks per pair in each country within each time period.

	Baseline	LIFE	Post-LIFE
England	17% (n=120)	31% (n=130)	37% (n=105)
Scotland	38% (n=50)	29% (n=38)	27% (n=37)
Wales	40% (n=5)	67% (n=9)	80% (n=10)

Table 5. Parameter estimates for the single best performing model assessing the probability of a site achieving or exceeding 0.7 chicks/pair. The reference value for Time Period is the Baseline period, while the reference value for Country is England.

Parameter	Estimate
Intercept	-3.764
Time Period (LIFE)	3.006
Time Period (postLIFE)	3.069
Count (ln)	0.647
Country (Scotland)	2.099
Country (Wales)	0.1175
Time Period (LIFE): Country (Scotland)	-2.249
Time Period (postLIFE): Country (Scotland)	-2.491
Time Period (LIFE): Country (Wales)	1.434
Time Period (postLIFE): Country (Wales)	1.858
Time Period (LIFE): Count (ln)	-0.675
Time Period (postLIFE): Count (ln)	-0.607

Table 6. Pairwise comparisons of the probability of fledging ≥ 0.7 young per pair, by Time Period within Countries for the top best-performing model using emmeans package (Lenth et al. 2023). Contrasts are performed while holding the covariate (colony size) at its mean value. The ratio between means for each group within the contrast is shown. A ratio >1 means that the first group has a higher mean than the second group, while a ratio <1 means that the first group has a lower mean than the second group. The null hypothesis is that the ratio =1 i.e. there is no difference between the means. P values are adjusted using Tukey method for comparing a family of 3 estimates, with tests performed on the log scale. The grey highlighted rows denote a significant contrast ($P < 0.05$).

Country	contrast	ratio	st. error	df	null	Z ratio	P value
England	Baseline / LIFE	0.553912	0.184713	Inf	1	-1.77153	0.18
	Baseline / postLife	0.40787	0.14101	Inf	1	-2.59401	0.03
	LIFE / postLife	0.736345	0.227068	Inf	1	-0.99249	0.58
Scotland	Baseline / LIFE	5.255075	3.325955	Inf	1	2.62156	0.02
	Baseline / postLife	4.925892	3.257624	Inf	1	2.41107	0.04
	LIFE / postLife	0.937359	0.615833	Inf	1	-0.09846	0.99
Wales	Baseline / LIFE	0.132056	0.161764	Inf	1	-1.65272	0.22
	Baseline / postLife	0.063627	0.082055	Inf	1	-2.13606	0.08
	LIFE / postLife	0.481815	0.519318	Inf	1	-0.67746	0.77

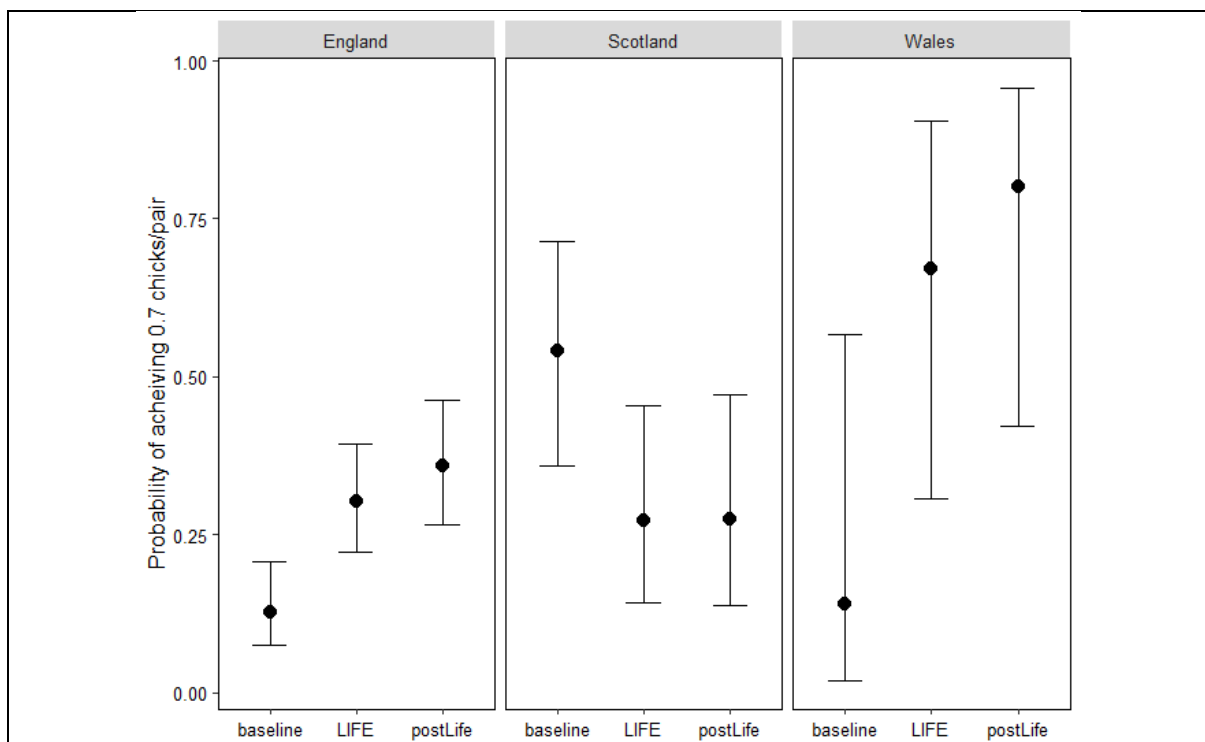
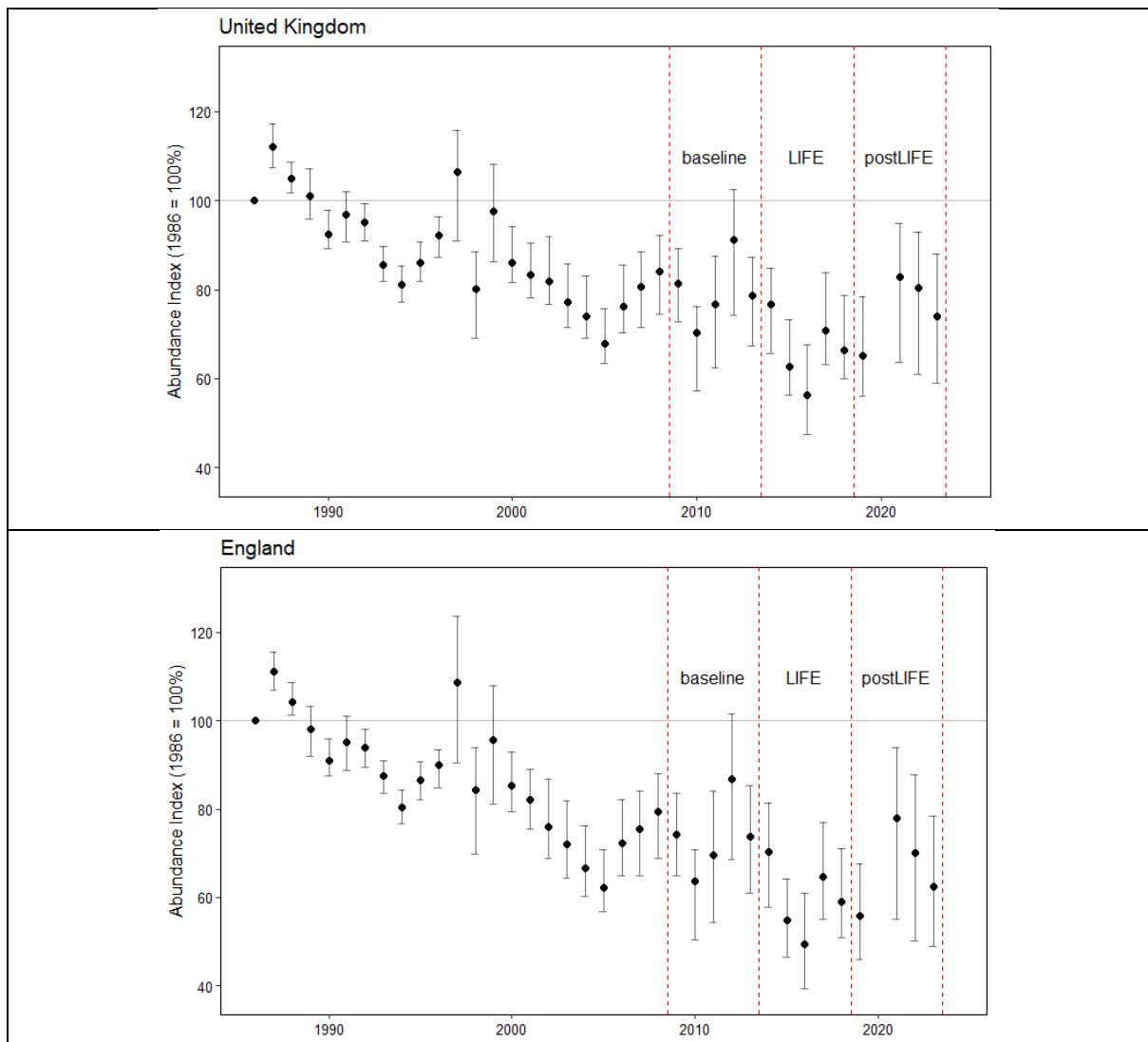


Figure 6. Predicted probability that a site achieved a breeding success value of at least 0.7 chicks per AON (the level required for population stability). Predictions are shown for the median colony size (17 AONs) across the dataset. See Appendix 2 for predictions for comparison colony sizes.

5.2. Population trend

There has been a continuous overall decline in long-term abundance over most of the SMP monitoring period for the UK, England and Scotland, and figures have largely remained below the 1986 reference value (Figure 7). However, the trend improved for the UK and England (where a large proportion of the UK Little Tern colonies are monitored) between 2019 and 2021, before dropping again in 2022. In 2023, the index values for the UK and England were 26% and 38% below the 1986 reference value, respectively, whilst the index value for Scotland was much lower at 83% below the 1986 reference value (Harris et al. 2024). The 23-year abundance trend for Little Terns between 2000-2023 was -14%, -27% and -72% for UK, England and Scotland respectively (Harris et al. 2024, no trend data are available for Wales).

We calculated the abundance trend during each of the three time periods based on the Harris et al. (2024) data (Table 8). Compared to the Baseline period, the abundance trend during LIFE continued to decrease across the UK as well as within England and Scotland. However, the abundance trend during the post-LIFE period was positive in England and across the UK while it decreased further in Scotland.



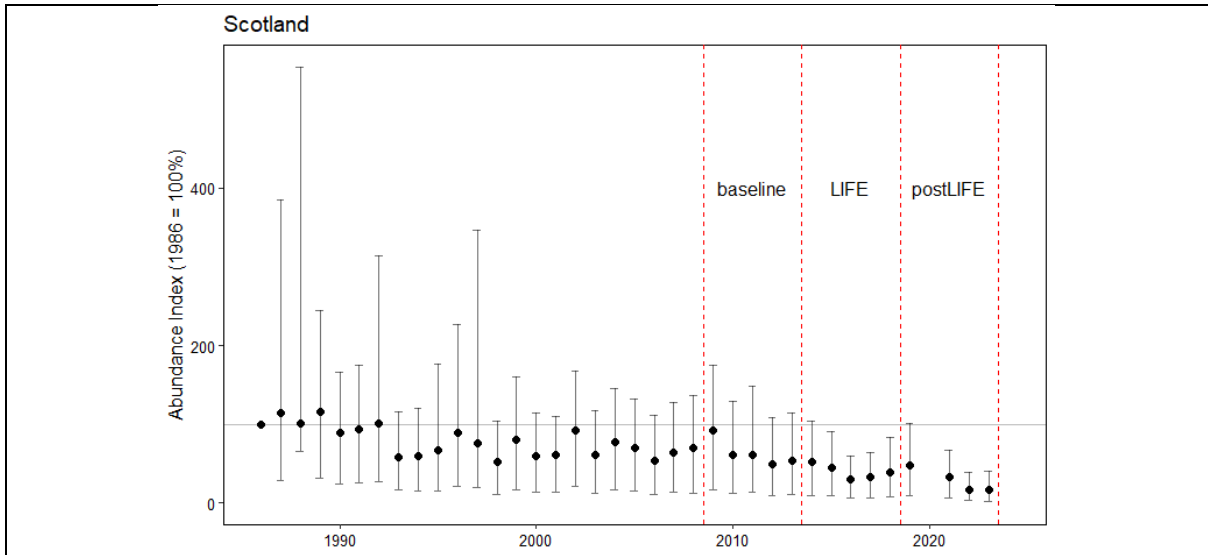


Figure 7. Population trend of Little Terns from 1986-2023 in UK (top), England (middle) and Scotland (bottom). Data are indices (points) with upper and lower confidence intervals (vertical bars) taken from Harris et al. (2024). The Baseline, LIFE and post-LIFE periods are indicated using vertical red dashed lines, with the 1986 index value shown by the horizontal grey line at 100%. The scale of the y-axis varies between plots. Note that the confidence intervals around the estimates for the UK and England fall almost entirely below the 1986 reference value from 1990 onwards, whereas in Scotland, this is only the case from 2015. No trend data are available for Wales.

Table 8. The 5-year Little Tern abundance trend within each Time Period for UK, England and Scotland. No trend data are available for Wales.

	Baseline	LIFE	Post-LIFE
UK	-2.8%	-10.3%	8.8%
England	-0.7%	-11.3%	6.7%
Scotland	-38.7%	-12.8%	-31.8%

6. Discussion

The country-level annual breeding success estimates from Harris et al. (2024) indicate that breeding success was largely stable during the Baseline and LIFE periods across the UK and in England, before then increasing during the post-LIFE period. In contrast, breeding success in Scotland declined between the Baseline and post-LIFE periods. Consistent with this, our statistical analyses using site-level data found evidence of an effect of Time Period on Little Tern breeding success, but the nature of that relationship depended on both country and colony size. For small colonies, there was an overall positive effect of Time Period on breeding success in all three countries. However, for median and large colonies, the positive effect of Time Period on breeding success was only apparent for England and Wales, with a negative effect in Scotland. However, there was a lot of uncertainty in our estimates and the increase in breeding success was only significant between the Baseline and post-LIFE period in England.

The overall positive effect of Time Period in England and Wales but not Scotland aligns with the fact that three of the four large-scale projects targeting Little Tern conservation (i.e. LIFE+, LOTE, and BNB) have all focussed on English sites, with the LIFE+ project also including the only two Little Tern Welsh sites. Although the Terner the Tide project is focussed on Scottish colonies, this only started in 2022 so the decline in breeding success between the Baseline and LIFE period in Scotland probably reflects a continuation of the existing overall decline in the absence of enhanced management and there has been little time for any benefits of Terner the Tide to be realised during the post-LIFE period. Overall, there were wide confidence intervals around predicted breeding success estimates such that, for the average colony size, the only significant effect of Time Period on breeding success was between the Baseline and post-LIFE periods in England.

All three of our best-performing breeding success models showed a positive effect of colony size on breeding success, but this effect was driven by an effect during the Baseline rather than LIFE or post-LIFE periods. Wilson et al. (2020) also found a positive effect of colony size on breeding success, in that case driven by reference sites (i.e. non-LIFE+ project sites) rather than those subject to enhanced management (i.e. LIFE+ project sites). They concluded this could be due to business-as-usual management of reference sites being focussed on larger colonies, while enhanced management at LIFE+ project sites also included smaller colonies such that there was no longer a relationship between colony size and breeding success. While our findings are in line with Wilson et al. (2020) i.e. the positive effect of colony size on breeding success is conditional on the nature of management application, it should be noted that the current analysis does not make a distinction between sites in terms of the level of management they received, only which Time Period (i.e. management period) they fall within.

We showed that the increase in breeding success over Time Period in England and Wales has also resulted in an increased probability of sites achieving the target level of breeding success required for population stability (0.7 chicks per pair, Cook & Robinson 2010). In England, there is now (post-LIFE) a 118% higher (i.e. more than double) proportion of site-years achieving 0.7 chicks per pair than during the Baseline period, while in Wales there has been a 100% increase. In contrast, in Scotland there has been a 26% reduction in the proportion of site-years achieving 0.7 chicks per pair compared to the Baseline period.

The abundance trend statistics from Harris et al. (2024) showed there has been a continuous overall decline in the long-term population trend of Little Terns during the SMP monitoring period from 1986-2023, both across the UK and in England and Scotland (no trend statistics were available for Wales). However, across the UK and in England, the abundance index reached its lowest point in 2016 and since then the index has generally increased, with the abundance trend during the post-LIFE period being positive. However, in Scotland, the abundance trend has continued to decline. The LIFE+ project started in 2014 and given that the age of first breeding in Little Terns is two or, more usually, three years old (Cramp 1985; Wilson et al. 2021), we would not expect any positive effects of that project to impact on breeding population abundance until at least 2016. The apparent turning point in abundance indices from 2016 in England but not in Scotland (which did not benefit from the LIFE+ project) is therefore consistent with there being a positive effect of enhanced management measures being in place since 2014 and that the increased probability of sites achieving breeding success of 0.7 chicks/pair in England and Wales, if sustained, may be sufficient to reverse the long term population decline.

The recently updated trend statistics for the UK and England (-14% and -27% respectively, Harris et al. 2024), indicate less severe declines than those based on the Seabirds Count census (-25% and -32% respectively, Burnell et al. 2023). In contrast, the -73% decline in Scotland presented in Harris et al. (2024) is much more severe than the -29% decline presented in Burnell et al. (2023). As the Harris et al. (2024) trend figures are derived from annual counts rather than from widely spaced censuses, they may provide more accurate figures than those presented in Burnell et al. (2023) (Harris et al. 2024). Crucially, most of the Seabirds Count census data for Little Terns were collected in 2018, so the Harris et al. (2024) trends include five years of more recent data that span the post-LIFE period. So, the less severe declines in the UK and England and more severe declines in Scotland presented in Harris et al. (2024) may also be partly due to the inclusion of more recent data during which colonies in England have had more time to benefit from enhanced management measures. Population trends of Little Terns breeding elsewhere in north-west Europe vary between countries. For example, for the countries with the three largest breeding populations in Europe (~1500-3500 pairs), the Little Tern population trend has been increasing in Italy and France but decreasing in Spain (Burnell et al. 2023). In Ireland, the most recent Seabirds Count census recorded 335 AONS, an increase of 102% since the Seabird 2000 census, while there was a 40% reduction in the Isle of Man to 12 AONS (Burnell et al. 2023).

In conclusion, the available evidence shows that the enhanced management measures put in place since 2014 in England and Wales have coincided with an improvement in breeding success and an increased probability that sites in these countries will achieve a level of breeding success sufficient for population stabilisation. Furthermore, the population trend in England is less negative than previously, and there are signs that it may be stabilising or perhaps even increasing. The continued decline in both breeding success and abundance in Scotland is consistent with large-scale enhanced measures only being implemented since 2022. However, it is important to note that we have not directly tested the effect of specific management regimes on breeding success. Rather we have assessed whether breeding success and abundance have shown an improvement that coincided broadly with when and where enhanced measures have been implemented. There is also a large amount of variation among sites and years in both abundance and breeding success and this is reflected in the large uncertainty associated with the population trends and breeding success estimates. However, overall, the direction of evidence points towards there being positive effects on Little Terns of the enhanced management measures put in place over the last decade on both breeding success and abundance.

We therefore recommend continuing with targeted efforts to improve the resilience of existing colonies, particularly increased protection from disturbance, increased predator and habitat management, and providing opportunities for new colonies to thrive in the face of habitat change and pressures of human disturbance.

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9. Appendix 1.

9.1. Alternative regional model

Here we present results of the analysis that used a four-level Region factor (where England was divided into northern and southern regions) instead of a three-level Country factor. Two equally best-performing models were identified (Table A1.1). The top model included Time Period, $\ln(\text{Count})$ and the interaction between them, as well as Region. The second model only included Time Period and $\ln(\text{Count})$. As the main reason for running this alternative model was to look in more detail at regional effects, we focus here on the top model. This showed that, after controlling for colony size, the number of fledglings was lowest in southern England compared to northern England, with Wales having the highest breeding success and Scotland having levels that lay in-between Northern England and Wales (Table A1.1), however this effect of Region was not significant (Table A1.2).

Wilson et al. (2020) previously found that colonies in East Anglia and the south of England had lower breeding success compared to the rest of the UK, and this was in line with the northern/southern regional differences observed previously by Cook & Robinson (2010) whereby breeding success was slightly declining in the southern region while the trend in the northern region was relatively stable. Therefore, the results of the top model align with what has been found previously. However, the evidence for an effect of Region is rather weak as the effect of Region in the top model was not significant, and the second top model (considered equivalent in performance) did not have any effect of Region. The weak evidence for an effect of Region still remaining may be because the enhanced conservation measures over the last decade have increased breeding success in East Anglia and the south of England to a point where the difference between colonies in the southern and northern regions is no longer significant.

Table A1.1. Parameter estimates for models investigating the effect of Time Period, Colony Size and Region on the number of Little Tern chicks fledged. Only the two best performing models are shown. The reference value for Time Period is the Baseline period, while the reference value for Region is Northern England.

		Model Rank	
		1	2
Conditional Model	Intercept	-1.247	-1.209
	Time Period (LIFE)	1.171	1.121
	Time Period (postLIFE)	0.930	0.893
	Count (ln)	1.199	1.165
	Region (Scotland)	0.138	
	Region (Southern England)	-0.239	
	Region (Wales)	0.284	
	Time Period (LIFE): Count (ln)	-0.285	
	Time Period (postLIFE): Count (ln)	-0.152	
Zero-inflation model	Intercept	0.157	-0.280
	Count(ln)	-0.496	-0.150
Df		13	10
logLik		-1483.8	-1487.5
AICc		2994.3	2995.5

Delta AICc	0.00	1.16
weight	0.459	0.257

Table A1.2. Pairwise comparisons between Regions for the top best-performing model using emmeans package (Lenth et al. 2023). Contrasts are performed while holding the covariate (colony size) at its mean value and are averaged over the levels of Time Period. The ratio between means for each group within the contrast is shown. A ratio >1 means that the first group has a higher mean than the second group, while a ratio <1 means that the first group has a lower mean than the second group. The null hypothesis is that the ratio =1 i.e. there is no difference between the means. P values are adjusted using Tukey method for comparing a family of 4 estimates, with tests performed on the log scale.

Contrast	Ratio	SE	df	null	Z ratio	P value
Northern England / Scotland	0.87	0.19	Inf	1	-0.64	0.92
Northern England / Southern England	1.27	0.22	Inf	1	1.39	0.51
Northern England / Wales	0.75	0.22	Inf	1	-0.97	0.77
Scotland / Southern England	1.46	0.26	Inf	1	2.08	0.16
Scotland / Wales	0.86	0.26	Inf	1	-0.48	0.96
Southern England / Wales	0.59	0.16	Inf	1	-1.96	0.20

9.2. Additional predictions of the probability of achieving 0.7 chicks/pair

The plot below is an expanded version to that shown in Figure 6, as it shows predictions for three different colony sizes, the 10th percentile (1 AON), 50th percentile (17 AONs) and 90th percentile (108 AONs). This allows visualisation of the different effects of colony size on the predictions for each country and time period. Specifically,

- For small colonies (1 AON), there is an overall positive effect of Time Period on the probability of achieving 0.7 chicks/pair, which is most marked for Wales. In Scotland there is a reduction in this probability between the LIFE and post-LIFE periods but the probability of achieving 0.7 chicks/pair during the post-LIFE period is still greater than that during the Baseline period.
- For median colonies (17 AONs), there is an overall positive effect of Time Period on the probability of achieving 0.7 chicks/pair in England and Wales. In Scotland, there is a large reduction in the probability of achieving 0.7 chicks/pair between the Baseline and LIFE periods, with the probability remaining stable thereafter.
- For large colonies (108 AONs), there is an overall positive effect of Time Period on the probability of achieving 0.7 chicks/pair in England and Wales (although there is a small reduction in this probability between the Baseline and LIFE periods in England). In Scotland, there is a large reduction in the probability of achieving 0.7 chicks/pair between the Baseline and LIFE periods, with the probability remaining stable thereafter.

